KNEE JOINT KINEMATICS DURING THE LANDING PHASE OF THE DOUBLE LEG JUMP IN ATHLETES WITH CHRONIC GROIN PAIN

by

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This thesis is presented in fulfilment of the requirements for the degree of Master in Physiotherapy (Structured) OMT in the Faculty of Medicine and Health Sciences at Stellenbosch University.

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March 2017

DECLARATION PAGE

By submitting this thesis, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that the reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2017

ABSTRACT

Introduction

Groin injuries are one of the most frequently occurring lower limb injuries, accounting for 5-28% of all sports-related injuries. Groin injuries have a significant morbidity rate and have potentially career-ending outcomes. There is a lack of research investigating the kinematics of the knee joint in athletes with chronic unilateral adductor-related groin pain.

Objective

The purpose of this study was to determine whether there are knee joint kinematic differences between athletes with chronic unilateral adductor-related groin pain and their healthy matched controls, during the landing phase of the double-leg jump.

Methodology

A cross-sectional study was conducted. Eighteen sports' participants were recruited from running, soccer and rugby clubs within the Cape Peninsula area. The three-dimensional (3D) knee joint kinematics of nine cases with chronic unilateral adductor-related groin pain and their nine asymptomatic matched controls were analysed. The cases were identified by means of a positive adductor squeeze test. Each participant performed three double leg jump-landings, during which the 3D knee joint kinematics was captured using an eight camera Vicon system, at the FNB-3D Vicon Laboratory at Stellenbosch University. The kinematic differences between the cases and their matched controls were measured from initial foot contact until the point of maximum knee flexion during the landing phase of the double-leg jump. Descriptive calculations were used to describe all outcome measures. Means and ranges were calculated to determine variability between participants. Means and standard deviations (SD), followed by a Student's two-tailed t-test was used to determine

significant differences between cases and controls. The effect size of outcomes with p-values equal to or less than 0.05 was calculated using Cohen's D.

Results

The main finding of this study was that there were no statistical significant differences in the knee joint kinematics of cases compared to their matched controls during the landing phase of the double-leg jump. In addition, there were no statistical significant differences in the knee joint kinematics in the inter-limb comparison in cases. However, cases had a tendency to demonstrate increased knee flexion and knee abduction angles in both the case-control and inter-limb comparisons, from initial foot contact to the point of maximum knee flexion, during the landing phase of the double leg jump.

Conclusion

Statistically insignificant differences were found in the knee kinematics between cases and their matched controls as well as in the inter-limb comparisons of cases. However, cases had a tendency to have increased knee flexion and abduction angles from initial foot contact to the point of maximum knee flexion, during the landing phase of the double leg jump. The sample size of this study could be the reason for the insignificant kinematic differences. Future research should better define the level of sport participation of the participating cases and controls or alternatively consist of a larger study sample, in order to determine kinematic differences.

Keywords: *Chronic unilateral adductor-related groin pain, knee joint kinematics, lower limb asymmetry, double-leg landing*

OPSOMMING

Inleiding

Liesbeserings is een van die mees algemene onderste ledemaat beserings, verantwoordelik vir 5-28% van alle sport-verwante beserings. Liesbeserings het ‘n aansienlike morbiditeitskoers en het potensiële loopbaan beëindegende uitkomste tot gevolg. Daar is ‘n gebrek in navorsing oor kniegewrig kinematika in atlete met kroniese unilaterale adduktor-verwante lies pyn.

Doelwit

Die doel van hierdie studie was om te bepaal of daar verskille is in kniegewrig kinematika tussen atlete met kroniese unilaterale adduktor-verwante liespyn en hul gesonde ooreenstemmende kontroles, tydens die landfase van die dubbelbeen sprong.

Metode

‘n Deursnee-studie was uitgevoer. Agtien sportdeelnemers van hardloop-, sokker- en rugbyklubs in die Kaapse Skiereiland was gewerf. Die drie-dimensionele (3D) kniegewrig kinematika van nege gevalle met kroniese unilaterale adduktor-verwante liespyn en hul nege asimptomatiese ooreenstemmende kontroles was geanaliseer. Die gevalle was geïdentifiseer deur middel van ‘n positiewe adduktor druk toets. Elke deelnemer het drie dubbelbeen sprong-landings uitgevoer, waartydens die 3D kniegewrig kinematika met ‘n agt kamera Vicon sisteem vasgevang was, by die FNB- 3D Vicon Laboratorium te Stellenbosch Universiteit. Die kinematiese verskille tussen die gevalle en hul ooreenstemmende kontroles was gemeet vanaf aanvanlike voet kontak tot die punt van maksimum knie fleksie tydens die landfase van die dubbelbeen sprong. Beskrywende berekeninge was gebruik om alle uitkoms maatstawe te beskryf. Gemiddelde en reekse was bereken om die veranderlikheid tussen deelnemers te bepaal. Gemiddelde waardes en standaardafwykings, wat gevolg was deur ‘n student t-toets wat gebruik was om merkwaardige verskille tussen gevalle en kontroles te bepaal. Die effekgrootte van resultate met p-waardes wat gelyk was aan of minder as 0.05 was bereken met Cohen’s D.

Resultate

Die hoof bevinding van hierdie studie was dat daar geen statisties beduidende verskille in die kniegewrig kinematika was van gevalle in vergelyking met hul ooreenstemmende kontroles tydens die landfase van die dubbelbeen sprong. Daarbenewens, was daar geen statisties beduidende verskille in die kniegewrig kinematika in die tussen ledemaat vergelyking in gevalle. Gevalle het egter ‘n neiging gehad om verhoogde knie fleksie en knie abduksie hoeke te toon in beide die geval-kontrole en tussen ledemaat vergelyking, vanaf aanvanklike voet kontak tot die punt van maksimale knie fleksie tydens, die landfase van die dubbelbeen sprong.

Gevolgtrekking

Onbeduidende statistiese verskille was bevind in die knie kinematika vergelyking tussen gevalle en hul ooreenstemmende kontroles, sowel as in die tussen ledemaat vergelyking van gevalle. Daar was egter ‘n neiging vir gevalle om verhoogde knie fleksie en abduksie hoeke te toon vanaf aanvanklike voet kontak tot die punt van maksimale knie fleksie, tydens die landfase van die dubbelbeen sprong. Die steekproefgrootte van hierdie studie kon die rede wees vir die onbeduidende kinematiese verskille. Toekomstige navorsing moet die vlak van sport deelneming van die deelnemende gevalle en die kontroles beter beskryf of alternatief uit ‘n groter studie steekproef bestaan, om kinematiese verskille te bepaal.

Sleutelwoorde

Kroniese unilaterale adduktor-verwante lies pyn; kniegewrig kinematika, onderste ledemaat asimmetrie, dubbelbeen land

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LIST OF ABBREVIATIONS

3D	Three Dimensional
AL	Adductor Longus
CKC	Closed Kinematic Chain
EMG	Electromyography
FAI	Femoro-acetabular Impingement
GM	Gluteus Medius
ICC	Intra-class Correlation Coefficient
PT	Physiotherapist
PIG	Plug-in-Gait
RFU	Rugby Football Union
ROM	Range of Motion
SD	Standard Deviation
VL	Vastus Lateralis
VM	Vastus Medialis

LIST OF DEFINITIONS

Asymmetry	Asymmetry is the deviation of one limb to replicate the exact movement of the other (Exell et al 2012).
Axis of Rotation	The axis which any segment of the body moves around in any direction (Levangie & Norkin 2011).
Closed Kinematic Chain	A system where both the proximal and distal ends are fixed and the application of force to one of this system will produce motion at all other segments of the stem in an anticipated manner (Karandikar & Ortiz Vargas 2011).
Eccentric Control	The resistive force produced by a muscle during active lengthening of the muscle to control the movement produced by the segment the muscle is acting on (Levangie & Norkin 2011).
Enthesis	The site where muscle tendons attach to bone (Levangie & Norkin 2011).
Homogeneity	The composition of a sample with components of the same type (OED Online, 2016).
Kinematics	It is the study of movement of any body segment over a period of time, irrespective of the force acting on it (Levangie & Norkin 2011).
Knee Abduction (valgus)	The movement of the tibia, in relation to the femur, away from the midline of the body (Levangie & Norkin 2011).
Knee Adduction (varus)	The movement of the tibia, in relation to the femur, towards the midline of the body (Levangie & Norkin 2011).
Mechanical Disadvantage	A muscle has a mechanical disadvantage when the magnitude of effort force it generates is greater than the resistive force of the segment it acts on (Levangie & Norkin 2011).
Morbidity	The frequency of a certain injury or disease within a specific population (OED Online, 2016).
Synergist	A muscle that assists the muscles which are designated to produce a specific movement (Levangie & Norkin 2011).

CHAPTER 1

INTRODUCTION

Groin injuries are one of the most frequently occurring lower limb injuries, accounting for 5-28% of all sports-related injuries (Sedaghati et al 2013; Alomar 2015). Furthermore groin injuries have a prevalence of 10-18% amongst soccer players and are indicated as one of the top six most common injuries by the Rugby Football Union (RFU) (Ryan et al 2014; Alomar 2015).

Groin injuries commonly occur in the following field-based sport codes such as football, ice hockey, running, rugby, Australian Rules football, Gaelic football, American football, basketball and cricket (Hölmich 2007; Gore et al 2014; Whittaker et al 2015). The association of groin pain with field-based sports are due to the biomechanical requirements during competition which increases the axial and rotational loads on the lower limbs up to 12 times the athlete's body weight (Ryan et al 2014).

The tbiofemoral, or knee joint, has three degrees of freedom of angular motion (Levangie & Norkin 2011). The stability of the knee joint relies profoundly on the soft tissue structures surrounding the knee joint, with the equilibrium between knee joint stability and mobility fluctuating as the knee joint flexes from full extension towards flexion (Levangie & Norkin 2011). Furthermore, the range of knee joint rotation and varus/ valgus motion is dependent on the range of knee joint flexion/ extension (Levangie & Norkin 2011).

The knee joint is exposed to large forces during activities of daily living and requires the integration of joint congruency, soft tissue restraint and muscle activation in order to stabilise the knee joint and dissipate the forces (Flaxman et al 2012). Flaxman et al (2012) reported that the vastus medialis (VM) and vastus lateralis (VL) muscles are classified as the general knee joint stabilisers during activities of daily living. The co-activation patterns of these joint stabilisers would stabilise the lower limb against hip adduction and subsequent valgus alignment of the knee joint (Flaxman et al 2012).

Groin pain normally presents with a gradual onset, however the onset can also be acute (Alomar 2015). Groin injury is the result of muscle overloading which produces microscopic lesions and a subsequent inflammatory reaction in the muscles, periosteum, or tendons located in the groin region (Renström & Peterson 1980).

Adductor-related muscle injuries, the adductor longus (AL) muscle specifically, accounts for 13-70% of sports-related groin injuries as the result of sudden eccentric loading (Millson 2012; Alomar 2015). However an imbalance in the strength ratio of the hip adductor and hip abductor muscles can place the athlete at risk for groin injury; especially in the presence of weaker hip abductor muscles (Nicholas & Tyler 2002; Morrissey et al 2012). In the presence of weaker hip abductor muscle strength, the athlete could exhibit decreased proximal control at the hip joint during closed chain activities with resulting kinematic changes at the distal knee joint; compensating for the lack of control proximally (Jacobs et al 2007; Morrissey et al 2012).

The tendon insertion area of the AL muscle have poorer vascularisation which negatively influences the healing process of lesions in this area (Macintyre et al 2006). The continuum of the injury and re-injury cycle, as athletes continue with neuromuscular and sport specific training, may not only result in a reduction in the athlete’s ability to perform or train, but can also result in chronicity of adductor-related groin pain (Whittaker et al 2015).

Chronicity of adductor-related groin pain has a higher incidence amongst athletes participating in weight bearing field sports which requires sprinting intervals during running, twisting and turning, dodging their opponents and kicking (Verrall et al 2005; Malliaris et al 2009). Although there remains a lack in consensus regarding the pathophysiology of chronic groin pain, it may be the result of acute groin pain, most likely due to injury of the AL muscle (Morissey et al 2012; Garvey & Hazard 2014).

Chronic groin pain is one of the most frequently diagnosed disorders amongst most football codes and has a significant morbidity rate. Chronic groin pain limits the function and performance of athletes and can persist for months or even years with career-limiting or career-ending outcomes for the sports athlete (Malliaris et al 2009; Garvey & Hazard 2014; King et al 2015).

Smith et al (2015) reported that several former studies suggested neuromuscular control being a modifiable risk factor for groin injury. Kinematic assessments (e.g. jump-landing tasks) have been used to determine the relationship between inadequate neuromuscular control and the risk of potential groin injury (Smith et al 2015). Kinematic studies employing jump-landing tasks aim at determining the effects of impact forces on the lower limbs during landing (Devita & Skelley 1992). However these assessments predominantly employed single-leg tasks in determining lower limb strength, which would intuitively be more appealing as most sports require unilateral lower limb propulsion (Hewit et al 2012b). However inter-limb strength of an athlete may vary greatly, based on leg dominance, muscle imbalances, coordination and previous injury (Hewit et al 2012b). The use of double-leg tasks for lower limb kinematic assessments, would be more suitable in determining inter-limb asymmetries. Therefore the aim of this study is to identify whether there are 3D kinematic differences between cases with chronic unilateral adductor-related groin pain and their matched controls, during the landing phase of the double leg jump.

CHAPTER 2

LITERATURE REVIEW

The focus of this review is to provide an overview and appraise the literature relating to: the prevalence, aetiology, diagnosis, risk factors, and impact of groin injuries in participants with chronic unilateral adductor-related groin pain and groin pain-related kinematics studies. The management of groin pain in sports athletes is a considerable challenge due its high frequency, prevalence, chronicity rate, and reduced ability for sports participation (Delahunt et al 2015). Therefore this topic is an important area for research in sports physiotherapy and sports medicine (Delahunt et al 2015).

A literature search was conducted from May 2014 until July 2016 using Google Scholar, Science Direct, Medline, Pubmed, and ProQuest databases. Key terms which were used included *'groin pain', 'adductor-related groin pain', 'chronic groin pain', 'knee kinematics', 'knee* AND *planar kinematics'*, and *'jump landing'* (Appendix A).

Prevalence

Groin pain has a common occurrence amongst athletes who participate in multidirectional sports and accounts for 10% of athletes who consult sports medicine centres (Alomar 2015). Groin injuries account for 5-28% of all sports-related injuries (Alomar 2015).

In their study investigating differential diagnosis for muscle-related groin pain, Renström & Peterson (1980) demonstrated the prevalence of muscle-related groin pain for the following muscles: adductor longus (AL) muscle-related pain 62%, rectus abdominus-related pain 22%, and iliopsoas and rectus femoris-related pain 16%.

Previous reports have demonstrated the high prevalence of groin pain in athletes who participate in sport codes such as 31% for soccer, 23% for rugby, 10 % for Australian Rules football, and 9.4% for Gaelic football (Orchard et al 2015; Ryan et al 2014). Participating in field-based sports such as rugby and soccer, predisposes the athlete to develop groin pain due to rapid acceleration and deceleration during running, kicking, twisting and turning, and changing direction. (Verrall et al 2005, Morissey et al 2012; Ryan et al 2014; Gore et al 2014; Whittaker et al 2015). These lower limb activities are pivotal in field-based sports (Verrall et al 2005, Morissey et al 2012; Ryan et al 2014; Gore et al 2014; Whittaker et al 2015). Athletes participating in these football codes are more prone to develop groin pain, having an annual incidence rate of 12-16% (Morissey et al 2012; Whittaker et al 2015).

Alomar (2015) reported that hip and groin injuries account for 12-16% of all injuries in adult soccer players. Adductor-related muscle strains among soccer players have been reported to have an incidence rate of 10 to 18% (Sedaghati et al 2013; Alomar 2015). The Rugby Football Union (RFU) has reported groin injuries to be one of the top six injuries commonly associated with professional rugby players and furthermore indicated it to occur more frequently during training (Ryan et al 2014). In addition the RFU's annual audit stated that the incidence rate of groin injuries to have progressed from 16th place in 2002 to 4th place in more recent years (Ryan et al 2014). O' Connor (2004) reported the incidence rate of groin pain in Rugby League players to be as high as 23% (Ryan et al 2014).

Chronic adductor-related groin pain is prevalent amongst athletes participating in soccer and rugby (Weir et al 2010). Glasgow et al (2011) reported the incidence of chronic groin pain in Gaelic football players to be as high as 24% (Ryan et al 2014). Furthermore chronic groin pain was reported as the second most common problem related to this sport code (Ryan et al 2014).

Aetiology

The occurrence of acute groin pain in athletes have commonly been believed to be due to pathology of the hip adductor muscle group, i.e. AL, adductor magnus, and adductor brevis, gracilis, pectineus and obturator externus (Cheatham et al 2014; Alomar 2015). Serner et al

(2015) demonstrated that acute groin pain was most frequently as a result of kicking, with 81% of kicking injuries related to the kicking leg and the injury most often related to the AL muscle. In order to stabilise the lower limb, by counteracting apprehension during closed chain sporting activities, the adductor musculature needs to exert a significant eccentric contraction force (Nicholas & Taylor 2002).

AL muscle strains are commonly caused by sudden eccentric loading on the AL muscle (Alomar 2015). Furthermore the AL muscle is most often the single source of groin pain due to its mechanical disadvantage and vulnerability during hip joint transitioning from a position of hip extension to hip flexion (Macintyre et al 2006; Cheatham et al 2014). It is hypothesised that injury risk of the AL muscle is most prevalent at maximum contractile force and maximal stretch rate during the swing phase of the kicking leg (Serner et al 2015). Change in direction is also a mechanism of injury frequently associated with acute groin injuries (Serner et al 2015). However there is a paucity in research on the mechanism associated with groin injuries during change of direction during running activities (Serner et al 2015).

The mechanism of chronic adductor-related groin injury/ pain can be as a result of repetitive overloading of the adductor muscle group which results in microscopic tearing or as a result of the secondarily formed scar tissue of the acutely strained adductor muscle (Schwellnus & Derman 1996). It is postulated that the forceful muscular contraction of the hip adductor muscle group results in tendinopathy (Schwellnus & Derman 1996). Tendinopathy occurs at the site of AL muscle insertion onto the pubic bone, or at the junction with the conjoint tendon at the aponeurotic pubic plate (Garvey & Hazard 2013). Chronic adductor-related groin pain can also be as a result of non-inflammatory tendinopathy or due to a poorly rehabilitated acute strain which has resulted in chronic or recurrent strains (Alomar 2015). Radiological investigation of individuals with chronic adductor-related groin pain have illustrated, amongst others, alteration of the adductor enthesis; i.e. thickening of the adductor enthesis, also known as enthesopathy (Schilders et al 2007; Morissey et al 2012).

Diagnosing groin injuries

Groin pain can either be localised or diffused, and possibly as a result of one, or a combination of musculoskeletal sources (Machota et al 2009). The resulting pain can be localised from the adductor musculo-tendinous unit and lower abdominal wall, or referred from the lumbar spine, hip joint, or anterior pelvis (Machota et al 2009). Furthermore other musculoskeletal conditions such as osteitis pubis, sports hernia, femoro-acetabular impingement (FAI), inguinal hernia, and obturator nerve neuropathy should be cleared as the cause for groin pain (Cheatham et al 2014; Alomar 2015).

In order to quantify adductor-related muscle strain as the underlying cause of groin pain, the athlete would have to present with pain on the inner side of the thigh, have apparent tenderness on palpation of the muscle belly, tendon, or insertion (Schwellnus & Derman 1996; Alomar 2015). In addition, the groin pain must be aggravated by resisted hip adduction or passive stretching of the adductor muscle (Schwellnus & Derman 1996; Alomar 2015). Nevin & Delahunt (2014) demonstrated the adductor squeeze test to be a valid tool in the assessment of groin pathology. A positive test would be the subjective reporting of pain and an indication of diminished adductor squeeze values (Nevin & Delahunt 2014). The test is performed in a crook lying position, with the hip flexed at 45 degrees, which is the optimal position for maximal stress to be applied to the converging tendons of the adductor muscle group (Nevin & Delahunt 2014).

Impact of groin injuries

Athletes participating in sports such as Australian Rules football and soccer have a higher incidence of developing sports-related chronic groin pain (Verrall et al 2005). The sequence of athlete injury and re-injury may not only lead to poor performance and missed opportunities for training or match participation, but also a tendency to develop chronic groin pain (Whittaker et al 2015). The development of chronic groin pain can also result in the cessation of the athletic career and furthermore influence the future mobility status of the affected individual (Whittaker et al 2015).

A high recurrence rate and a diminished level of sporting ability, are some of the challenges athletes with chronic adductor-related groin pain and their managing clinicians face (Nevin & Delahunt 2014). The morbidity level of athletic groin pain, in terms of time lost as a result of injury, rates second to fractures and joint reconstruction (Gore et al 2014). The level of morbidity related to chronic groin pain is serious, with reference to time lost due to injury, disability and the substantial costs related to medical care (Paajanen et al 2011). In addition, the athletes' inability to return to sports may consequently have considerable economic impact on professional sporting clubs and organisations, in view of loss of income as a result of lack of team performance. (McSweeney et al 2012). Identifying anatomical and biomechanical causes for hip and groin injuries is crucial as it is one of the most complex and controversial areas in the musculoskeletal system (McSweeney et al 2012).

Anatomy and biomechanics of the hip adductors

Individuals who present with decreased hip abductor strength, may exhibit decreased hip control and subsequent altered knee kinematics (Jacobs et al 2007). It is postulated that proximal hip control is essential for neuromuscular control of the inferior knee joint (Jacobs et al 2007). Generally the musculature surrounding the hip joint are mechanically disadvantaged, due to their relatively short lever arms that have to generate considerable contraction force across the hip joint (Anderson et al 2001).

The primary role of the hip adductor muscle group is adduction of the thigh during open chain activities, and to provide stability to the lower limb during closed chain activities when absorbing forces endured, such as the landing phase of a jump (Nicholas &Tyler 2002). The AL muscle also has a secondary role of acting as a synergist during hip flexion and hip internal rotation (Nicholas & Tyler 2002). Due to its multi-planar activation pattern the AL muscle respectively has moment arms of 7.1cm for adduction, 4.1cm for flexion and 0.7cm for internal rotation in an anatomic or neutral position (Neumann 2010).

The activation force required by a muscle is dependent on the muscle's line of force in relation to the joint's axis of rotation on which it acts; i.e. it is dependent on the plane of movement of the joint it act on (Neumann 2010). The line of force of the AL muscle is based on its anatomical position; change in position will influence its action, and thus will change this muscle's action from a primary to secondary role (Neumann 2010).

Risk Factors

Common risk factors

Risk factors in sports injuries are factors that influence the prevalence of sports-related injuries (Ryan et al 2014). Although activities entailing sprinting and rapid change in speed and direction have more commonly been associated with groin pain, kicking and bodily contact places the athlete at an even higher risk for the development of groin pain (Sedaghati et al 2013).

Risk factors can be: (1) intrinsic, which are person-related such as age, (2) extrinsic, which are related to the environment such as the playing surface, (3) modifiable, which are factors which can be altered to reduce injury prevalence such as strength, and (4) non-modifiable, which are factors which cannot be altered to reduce injury prevalence such as previous injury (Ryan et al 2014).

Modifiable risk factors such as lack of sport-specific training, high level of play, endurance, decreased hip adductor muscle strength, diminished hip abduction range of motion (ROM), and balance are likely to increase the risk of groin injury in sport (Maffey & Emery 2007; Engebretsen et al 2010; Alomar 2015). Macintyre et al (2006) reported a 32-44% recurrence rate for adductor strain in athletes who previously sustained adductor-related injuries.

Other risk factors

Other risk factors, predisposing the athlete in developing adductor-related groin pain, include: higher league of sports participation and an increased body mass index (BMI) (Whittaker et al 2015).

Biomechanical risk factors

Effective landing from a double leg jump would require an eccentric muscle activation pattern in a distal to proximal sequence of the lower limb in order to provide multi-planar joint stability and dissipate the energy from the impact. Wu et al (2013) reported that landing performance is primarily determined by the eccentric control of the lower limbs' extensor musculature. Minor adductor-related groin injuries can result in muscle imbalances and resultant altered biomechanics (McSweeney 2012). The resultant altered biomechanics can worsen the injury as the athlete persists with training and sport participation (McSweeney 2012). It has been reported that athletes with chronic groin pain present with motor control imbalances, which leads to poor load transfer between the pelvis and the lower limbs and subsequent repetitive strain of soft tissues in the groin area (Morissey et al 2012).

In soccer, the action of kicking a ball requires a backswing phase, where the athlete swings the leg into hip extension (Kellis & Katis 2007). The forward motion that follows the backswing of the leg, requires a combination of hip flexion, adduction while the hip remains externally rotated (Kelis & Katis 2007). It can be hypothesized that during the action of kicking, the AL muscle would have to exert a considerable amount of contraction force as it has to flex (secondary role) and adducts (primary role) the hip joint, while it is in a mechanically disadvantaged position; lengthened in the position of hip external rotation. . Therefore, when abnormal biomechanics are employed to execute sport specific movements, the stresses placed on the adductor muscles, specifically the AL muscle, increases and could thus result in muscle/ tendon strains.

Kinematic Studies

Orchard (2001) and Knapik et al (1991) suggested that inter-limb asymmetry can be a risk factor for sustaining lower limb injuries (Gore et al 2014). Inter-limb asymmetry can be a natural occurrence in athletes, a result of limb dominance which could result in stress of specific tissues, or as a manifestation of sport specific stresses (Hewit et al 2012a; Gore et al 2014).

The dominant limb is favoured during sport activity-related tasks and is likely to have greater muscle mass and strength compared to the contralateral limb (Hewit et al 2012a; Gore et al 2014). It can therefore be hypothesised that the weaker contralateral limb has a higher injury risk during dynamic activities which would require eccentric control.

Previous studies on inter-limb asymmetries have demonstrated that elite athletes, participating in field based sports such as soccer, had greater levels of asymmetry compared to healthy individuals (Gore et al 2014). However, there is a lack of investigations aimed at determining whether kinematic and kinetic asymmetry is of significance to chronic groin pain in athletes (Gore et al 2014).

Verrall et al (2005) made use of clinical single measurement goniometry to determine hip joint internal and external ROM differences in individuals with chronic groin pain. Outcomes of their study demonstrated a significant decrease in hip external rotation and a tendency for a decrease in internal rotation compared to their matched controls and statistically insignificant differences in the inter-limb assessment of cases. (Verrall et al 2005). However the hip joint was investigated in isolation, which was reported as a weakness in their study (Verrall et al 2005).

Thorborg et al (2014) made use of handheld dynamometry to determine hip adductor strength in individuals with adductor-related groin pain. Reported findings were indicative of decreased eccentric hip adductor strength in cases compared to their matched controls;

however no inter-limb comparison was made (Thorborg et al 2014). Furthermore, Thorborg et al (2014) reported that decreased eccentric hip adductor strength did not directly relate to altered hip joint ROM; however hip joint ROM was assessed with goniometry (Thorborg et al 2014).

Morrissey et al (2012) made use of electromyography (EMG) during a pelican/ stork stance to determine altered muscle activation patterns of the gluteus medius (GM) and AL muscles in individuals with groin pain. Reported findings were indicative of a significant reduction in GM:AL muscle activation in the injured stance leg of cases with groin pain compared to their cases (Morrissey et al 2012). In addition, they also reported a reduction in GM muscle activity in the uninjured leg of cases in an inter-limb comparison (Morrissey et al 2012).

Reported inter-limb asymmetry assessments have used methods such as isokinetic dynamometry, jump and running tests (Gore et al 2014). However the use of isokinetic dynamometry have been criticised as it does not reproduce sport specific movement and thus may not be sensitive to measure asymmetry (Gore et al 2014). Gore et al (2014), suggested that the use of a three dimensional (3D) assessment may provide better understanding of asymmetrical loading patterns when an athlete performs a particular sporting activity.

Vertical jump tasks, and deviation thereof, are commonly employed in the assessment of lower limb muscle strength (Hewit et al 2012b). Furthermore vertical jump tasks for assessment have been associated with reliable results due to its supposedly high specificity to sporting activities (Hewit et al 2012b). The fixed proximal and distal ends of the lower limbs during jump-landing tasks, results in the lower limbs to function as a closed kinematic chain (CKC) (Karandiker & Ortiz Vargas 2011). Jump tasks subjects the knee joint to large joint loading forces during the landing phase to effective resist joint collapse of the lower limb during landing (Devita & Skelly 1992; Flaxman et al 2012).

The impact force on landing requires force dissipation in a sequence from distal to proximal (Karandiker & Ortiz Vargas 2011). It can be considered that a lack in force dissipation distally would result in an inverse pattern of force dissipation, i.e. proximal to distal. In addition, decreased hip abductor strength may result in a tendency for the athlete to present with a decreased or lack in ability of proximal hip control and increase loading of the hip adductors, amongst other structures (Jacobs et al 2007).

Single-limb tasks are commonly preferred for kinematic testing as most sports require unilateral lower limb propulsion (Hewit et al 2012b). However single limb tasks cannot effectively assess inter-limb asymmetry of an athlete which may vary greatly, based on leg dominance, muscle imbalances, previous injury, and coordination (Hewit et al 2012b). Previous lower limb kinematic studies, which studied the double leg jump, included healthy participants only, excluded inter-limb comparisons and studied knee kinematics in relation to anterior cruciate ligament injury (Yeow et al 2009; Yeow et al 2010; Norcross et al 2013a; Norcross et al 2013b). Studies related to groin pain, studied the relation of groin pain to proximal control surrounding the hip joint and hip joint ROM (Verrall et al 2005; Morrissey et al 2012; Thorborg et al 2014).

Biomechanical studies related to groin pain have aimed at reviewing the kinematics of the hip joint and its surrounding structures. Furthermore these studies employed single limb assessment which could not identify limb asymmetries that could influence the athlete's biomechanics during sporting activities (Verrall et al 2005; Morrissey et al 2012; Thorborg et al 2014). Studies which included double-limb assessment tasks included homogenous populations and aimed at describing biomechanics related to knee joint injuries (Yeow et al 2009; Yeow et al 2010; Norcross et al 2013a; Norcross et al 2013b).

Therefore this study will be of great value in determining whether the knee kinematics differ in individuals with chronic unilateral adductor-related groin pain when compared to matched healthy/pain-free controls. Furthermore this study will be able to suggest whether asymmetry can be considered as an underlying cause for altered kinematics of the lower limb and subsequent groin injury.

CHAPTER 3

METHODOLOGY

Study Design

A cross-sectional research design was used for this study.

Study aim

The aim of this study was to determine whether there are knee joint kinematic differences among athletes with chronic unilateral adductor-related groin pain during the landing phase of the double-leg jump, compared to their healthy controls.

Study objectives

The objectives of this study are to:

1. Describe the kinematics of the knee joint using 3D motion analysis during the landing phase of the double-leg jump;
2. Determine whether there are inter-limb asymmetries in cases with chronic unilateral groin pain; and
3. Determine whether there are knee joint kinematic differences between cases and their matched controls during the double leg jump.

Research Question

What are the biomechanical differences of the knee joint in athletes with chronic unilateral adductor-related groin pain during the double leg landing, compared to healthy controls?

Participants

This study was a sub-study of a larger study (Janse van Rensburg et al, In Review); this resulted in an extensive physical examination although all of the information was not necessarily used during this specific sub-study. The original study by Janse van Rensburg et al (In Review), aimed at determining trunk and lower quadrant kinematics during a single-leg drop-landing in athletes with chronic groin pain. During the original study kinematic data for double-leg jump-landing in athletes with chronic unilateral adductor-related groin pain were captured. However, the double-leg jump-landing data was not analysed. Participants for this study were recruited from cycling, running, rugby and soccer clubs within the Cape Peninsula area. During the recruitment process, clubs, based on clientele and listed under Cape Peninsula Club Rugby and Cape Town Soccer Club listings, were contacted by the researches in order to determine interest to participate. Clubs who indicated interest to participate were then visited by the researchers in order to identify and screen potential participants.

In total twenty eight participants (fourteen cases and fourteen matched controls) were recruited for the 2013 and 2015 studies. Respectively twenty participants (ten cases and ten controls) were recruited for the 2013 study and eight participants (four cases and four controls) were recruited for the 2015 study; the 2015 study was a sub-study to the 2013 study.

The collective study sample consisted of males only, between the ages of 19 and 55 years (Figure 1). To meet the aim of this particular study, the results of only the group of participants who participated in field sports and met the criteria for the chronic unilateral adductor-related groin pain study, will be presented. The study sample will be described under *sample description* under the *Results* chapter (n= 18).

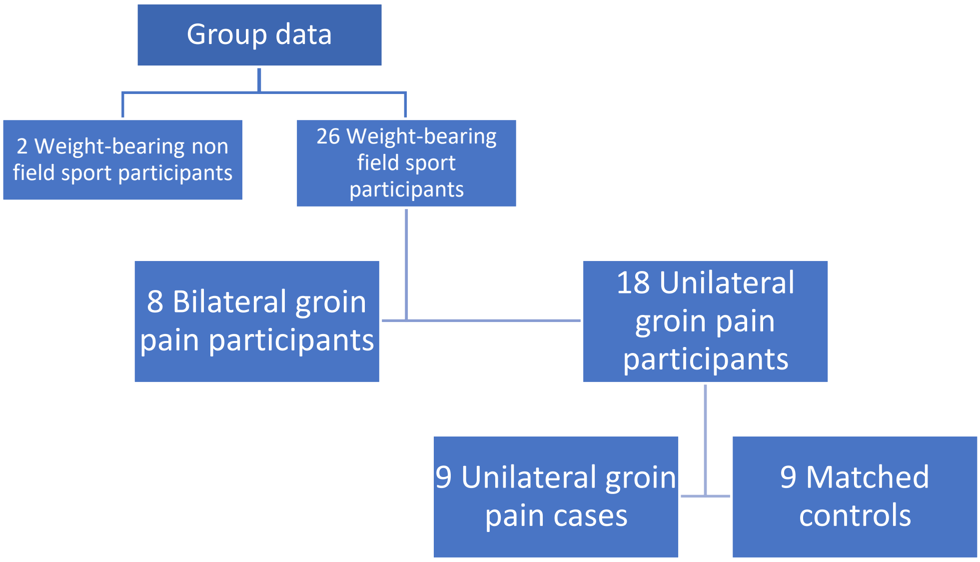

Figure 1: Study sample data.

None of the participants had a history of spinal, pelvis, or lower limb pathology; except for the cases who presented with chronic unilateral adductor-related groin pain. The cases their and their asymptomatic controls were matched according to age, sports code and sports club. The nine cases were examined by two physiotherapists to ensure they met the inclusion and exclusion criteria as stated in Table 1.

Table 1: Inclusion and exclusion criteria for cases and their matched controls.

	Cases	Matched controls
Inclusion Criteria	Soccer and rugby players at club level. Runner at club level.	Soccer and rugby players at club level. Runner at club level.
	Males between the ages of 18-55 years.	Males between the ages of 18-55 years.
	Chronic unilateral adductor-related groin pain located at the proximal insertion of the adductor muscles on the pubic bone, of any intensity for more than 3 months.	No history of groin pain
	Groin pain during or after sporting activity.	
	Positive Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011).	Negative Adductor squeeze test with a sphygmomanometer (Delahunt et al 2011).
	Participating in sport or physical training despite the groin injury.	Participating in sport or do form of physical training.

	Good general health.	Good general health.
Exclusion Criteria	Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last 12 months.	Any orthopaedic surgical procedure of the lower quadrant and lumbar spine within the last 12 months.
	Positive findings on previous imaging for bony lesions.	Positive findings on previous imaging for bony lesions.
	Any disease that has an influence on functional ability/ movement e.g. Ankylosing Spondylosis, Scheuerman's disease, Rheumatoid Arthritis, Muscular Dystrophy and Paget's disease.	Any disease that has an influence on functional ability/ movement e.g. Ankylosing Spondylosis, Scheuerman's disease, Rheumatoid Arthritis, Muscular Dystrophy and Paget's disease.
	History of spinal, lower limb or pelvis pathology other than groin injury.	History of spinal, lower limb or pelvis pathology other than groin injury.
	Symptoms of prostatitis or urinary tract infection.	
	Clinical suspicion of nerve entrapment syndrome	
	Palpable inguinal or femoral hernia.	

The main inclusion criteria for cases were a positive adductor squeeze test on initial assessment. The validity and reliability of the adductor squeeze test as screening test for hip adductor strains/ injuries, has been demonstrated when performed in crook lying, with the hips and knees in 45 degrees flexion (Appendix B) (Mens et al 2002; Verrall et al 2005; Crow et al 2010; Nevin & Delahunt 2014). The inclusion criteria for the matching controls were similar to that of the cases, except that they should have had no history of groin pain and a negative adductor squeeze test on initial assessment. In addition special tests were performed on initial assessment to clear the sacro-iliac and hip joints, as well as an inguinal hernia (Morelli & Weaver, 2005). All participants provided informed consent to participate (Appendix C). The protocol for this study was approved as an amendment to the study conducted in 2013 (Janse van Rensburg et al, In Review) by the Human Research Ethics Committee of the Faculty of Medicine and Health Sciences (FMHS), Stellenbosch University (S12/10/265) (Appendix D).

Instrumentation

The Vicon motion analysis (Ltd) (Oxford, UK) system is a 3D system which is used in a wide variety of ergonomics and human factor applications. It is capable of capturing 250 frames-per second at full frame resolution (1 megapixel). For this study an eight camera T-10 Vicon (Ltd) (Oxford, UK) system, with Nexus 1.4 116 software, was used to capture trials. The T-10 is a motion capturing system, with a unique combination of high speed accuracy and resolution (Windolf et al, 2008).

A 3D Bertec force plate (Bertec Corporation Ltd) was used to determine foot contact during the landing phase of the double leg jump.

Knee kinematics was calculated according to the Plug-in-Gait (PIG) model (Vicon Motion systems, 2010). In the PIG model the knee angles, force, moment and power are defined between the thigh and the lower leg (Vicon Motion systems, 2010).

Testing Protocol

All eighteen participants attended the FNB-3D Motion Analysis Laboratory once, scheduled on separate appointments of approximately 90 minutes. The 2013 data were collected over a period of one month and the 2015 data were collected over a nine week period. Prior to the motion analysis assessment, anthropometrics (namely weight, height, leg length, and knee and ankle width) were measured and a physical examination (Appendix E) was conducted. Leg length was measured from the anterior superior iliac spine to the medial malleolus. The physical examination was aimed at evaluating leg dominance and to determine any abnormalities. The examination consisted of postural observation (feet, knees, pelvis, lumbar and thoracic spine); functional movement tests (namely lunges, squats); and passive ROM assessment of the hip, knee and ankle (namely flexion, extension, adduction, abduction, internal, external rotation, plantarflexion and dorsiflexion) was assess with a goniometer. Range of motion measurement with a universal goniometer during passive hip flexion; extension; internal rotation and external rotation noted an ICC of 0.80, producing good reliability of the universal goniometer (Roach et al 2013).

The maximum joint ROM data of respective participants were entered as normative values, which would be available should distinctive variances be validated. The physical examination of the participants for the 2013 study was completed by the 2013 study researchers. Following consultation with the 2013 researchers, the 2015 researchers used the same physical assessment protocol in order to ensure good reliability between test occasions.

Nineteen retro-reflective markers were placed on bony landmarks according to the lower limb Plug in Gait (PIG) model (Appendix F). The application of the markers was done by the laboratory physiotherapist (PT). This PT was trained in marker placement and understood the PIG model; therefore the good reliability between test occasions could be ensured (r=0.8-0.97 for all three planes).

The test was demonstrated to the participants by the researcher and participants were allowed one practice round to perform the double-leg jump. Participants received a verbal instruction from the researcher prior to each test (Table 2).

Table 2: Instructions for performing a double leg jump.

Double leg jump
• Stand on floor on indicated area, with arms at your sides.
• When indicated, jump as high and forward, to the best of your ability, landing on the indicated area.
• Hold your landing position for 3 seconds.

Each participant performed three double-leg jumps. Participants were asked to perform a maximum effort jump from a neutral standing position and land with both feet simultaneously, with the indicated leg's foot landing on the embedded force plate. Data was collected for three double-leg jumps per leg (i.e. 6 jumps for each participant). For each jump participants were positioned at a distance of 60% of their leg length from the border of the force plate. The starting leg was randomized (using the coin-tossing method) by one of the researchers (Figures 2 and 3).

Figure 2: Starting position for the double leg jump.

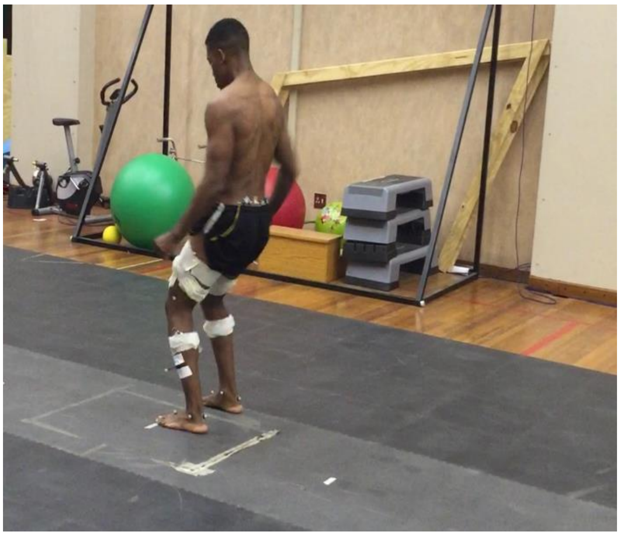

Figure 3: End position for the double leg jump.

Data Processing

Gap filling was performed using the standard Wolt ring filter supplied by Vicon (Vicon System, 2010). The events for foot contact and the point of maximum knee flexion were calculated automatically using Matlab Version R2012b. Joint kinematics were calculated using the PIG-model and filtered with a 4^{th}-order Butterworth filter at a 10Hz cut-off frequency. Data was exported to Matlab to extract the parameters of interest.

Kinematic Outcomes

In order to determine differences in knee kinematics of participants the following parameters were used:

- Knee kinematics at initial foot contact during the landing phase of the double-leg jump, in the respective planes of movement.

  - Initial foot contact was expressed as the moment in the landing phase when any part of the foot came in contact with the force plate and the vertical forces imposed on the force plate exceeded 30N.
- Knee kinematics at the point of maximum knee flexion, in the respective planes of movement.
  - The point of maximum knee flexion was expressed as the moment before commencement of knee extension and returning to the neutral position.
- Knee joint ROM from initial foot contact until the point of maximum knee flexion during the landing phase of the double-leg jump.

Data Analysis

The group data was divided into subgroups in order to stream a homogeneous data set (Figure 1) for the comparisons.

The homogeneity of the study sample was indicative of cases and their matched controls.

The demographic information of participants were expressed with descriptive statistical calculations (means and ranges to indicate variability). Descriptive statistical calculations were used to calculate all outcome measures (means and standard deviations (SD)). A Student's two-tailed t-test was done for all outcome measures to determine significant differences between the cases with chronic unilateral adductor-related groin pain and controls. A statistical significant outcome was expressed as having a p-value equal to/ or less than 0.05. The effect size was calculated using Cohen's D (Thalheimer & Cook, 2002). Interpretation of the effect size is illustrated in Table 3.

Table 3: Cohen's D value

Relative Size of Cohen's D	
Small effect	>=.15 and <.40
Medium effect	>=.40 and <.75
Large effect	>=.75 and <1.10
Very large effect	>=1.10 and <1.45
Huge effect	>1.45

Sample Size Calculation

A post hoc sample size calculation was calculated using G.-Power Version 3.1 statistical power analysis program. Considering a large effect with a Cohen's statistic of at least 1 and sample size of 18 (which included the nine chronic unilateral adductor-related groin pain subjects and their controls) in the unilateral subgroup, the power was calculated to be 97%. A power calculation of 0.9 or 90% is considered as sufficient and generally accepted for clinical application (Fitzer & Heckinger 2010).

CHAPTER 4

RESULTS

Sample Description

The collective demographic data of the eighteen male participants (nine cases with chronic unilateral adductor-related groin pain and nine matched pain-free controls) who participated in this study is presented in table 4. The participating sample consisted of matched pairs, participating in weight-bearing sports activities such as rugby (twelve), soccer (four) and running (two).

Age, weight and height were not significantly different between the cases and their matched controls.

Table 4: Participant demographic information

	CASES (n=9)	CONTROLS (n=9)
Age (yrs.) Mean	24.8	23.4
Age: Range	19 – 38	20 – 28
Weight (kg) Mean	85.0	89.9
Weight: Range	61.6 – 129.1	73.1 – 133.7
Height (m) Mean	1.8	1.8
Height: Range	1.7 – 1.9	1.6 – 1.9

Kinematic differences

Table 5 and 6 respectively present the kinematic differences related to:

a) The knee angle at initial foot contact;

b) The knee angle at lowest vertical point (maximum knee flexion); and

c) Total knee joint range of motion (ROM) during the landing phase of the double-leg jump.

Table 5 presents the kinematic differences between the affected side of cases and the corresponding side of their matched controls.

Table 5: Kinematic differences between the affected side of cases (n=9) and the corresponding side of their matched controls (n=9).

	CASES (n=9)	CONTROLS (n=9)	p VALUE
	SAGITTAL PLANE[1]		
Knee angle at foot contact (degrees) MEAN (SD)	23.6 (±6.2)	19.6 (±5.6)	p= 0.2
Total ROM (degrees) MEAN (SD)	49.8 (±18.2)	38.7 (±11.8)	p= 0.1
Angle at lowest vertical point (degrees) MEAN (SD)	73.4 (±20.4)	58.3 (±14.6)	p= 0.1
	FRONTAL PLANE[2]		
Knee angle at foot contact (degrees) MEAN (SD)	4.0 (±6.1)	5.3 (±6.1)	p= 0.7
Total ROM (degrees) MEAN (SD)	11.2 (±10.6)	6.5 (±5.1)	p= 0.2
Angle at lowest vertical point (degrees) MEAN (SD)	15.2 (±12.2)	11.8 (±8.1)	p= 0.5
	TRANSVERSE PLANE[3]		
Knee angle at foot contact (degrees) MEAN (SD)	-5.1 (±10.8)	-3.5 (±11.4)	p= 0.8
Total ROM (degrees) MEAN (SD)	12.2 (±8.1)	10.5 (±6.6)	p= 0.6
Angle at lowest vertical point (degrees) MEAN (SD)	7.1 (±9.9)	7.0 (±11.2)	p= 1.0

There were no statistically significant kinematic differences between the affected side of cases and the corresponding side of their matched controls. However there was a tendency

[1] Sagittal Plane: Knee Flexion (+) Extension (-)

[2] Frontal Plane: Abduction/ Valgus (+) Adduction/ Varus (-)

[3] Transverse Plane: Internal Rotation (+) External Rotation (-)

for cases to have an increased total knee joint flexion ROM from initial foot contact to the point of maximum knee flexion compared to their matched controls.

Furthermore cases also demonstrated a greater total knee joint abduction ROM from initial foot contact to the point of maximum knee flexion.

Table 6 present the kinematic differences in the inter-limb comparison of cases.

Table 6: Kinematic differences between the affected and unaffected lower limb of cases (n=9).

	AFFECTED SIDE (n=9)	UNAFFECTED SIDE (n=9)	p VALUE
	SAGITTAL PLANE[4]		
Knee angle at foot contact (degrees) MEAN (SD)	23.6 (±6.2)	21.7 (±5.4)	p= 0.5
Total ROM (degrees) MEAN (SD)	49.8 (±18.2)	50.03 (±17.5)	p= 1.0
Angle at lowest vertical point (degrees) MEAN (SD)	73.4 (±20.4)	72.0 (±20.4)	p= 0.9
	FRONTAL PLANE[5]		
Knee angle at foot contact (degrees) MEAN (SD)	4.0 (±6.1)	3.4 (±4.3)	p= 0.8
Total ROM (degrees) MEAN (SD)	11.2 (±10.6)	10.5 (±7.4)	p= 0.9
Angle at lowest vertical point (degrees) MEAN (SD)	15.2 (±12.2)	13.9 (±8.2)	p= 0.8
	TRANSVERSE PLANE[6]		
Knee angle at foot contact (degrees) MEAN (SD)	-5.1 (±10.8)	-4.5 (±8.5)	p= 0.9
Total ROM (degrees) MEAN (SD)	12.2 (±8.1)	13.0 (±5.4)	p= 0.8
Angle at lowest vertical point (degrees) MEAN (SD)	7.1 (±9.9)	8.5 (±9.4)	p= 0.8

[4] Sagittal Plane: Knee Flexion (+) Extension (-)

[5] Frontal Plane: Abduction/ Valgus (+) Adduction/ Varus (-)

[6] Transverse Plane: Internal Rotation (+) External Rotation (-)

There were no statistically significant kinematic differences in any of the three movement planes between the affected and unaffected legs of cases. However there was a tendency for the affected side of cases to demonstrate a greater total knee joint flexion ROM from initial foot contact to the point of maximum knee flexion compared to the unaffected side. In addition the affected side of cases also demonstrated greater total knee joint abduction ROM from initial foot contact to the point of maximum knee flexion.

Difference in knee angles from foot contact to peak knee flexion

Sagittal Plane

Figures 4 and 5 illustrate the difference in knee flexion from initial foot contact to peak knee flexion.

Figure 4 illustrates that the knee flexion from initial foot contact to the point of maximum knee flexion was greater on the cases' affected side compared to the corresponding side of their matched controls.

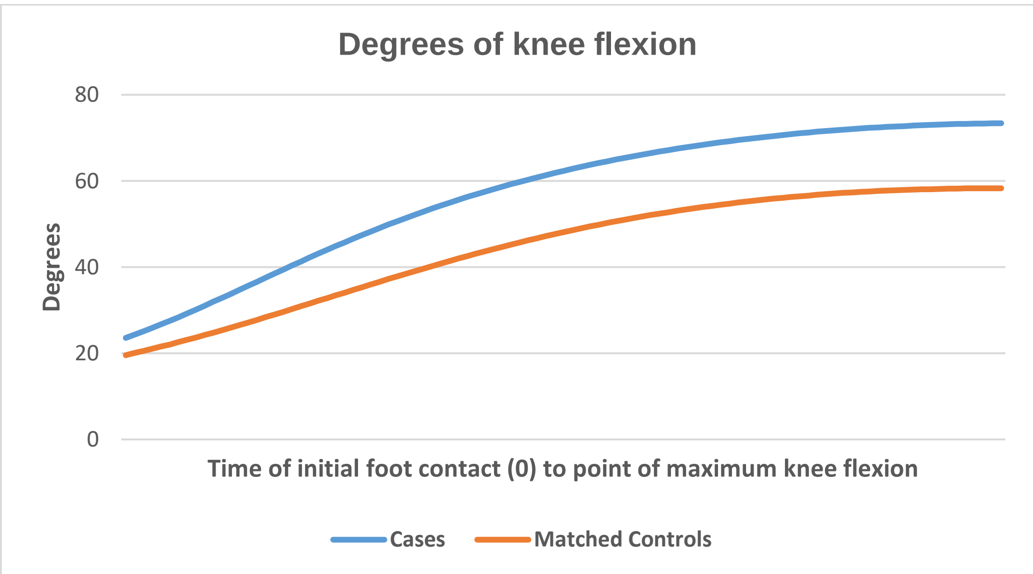

Figure 4: Cases' and their matched control comparison of knee joint flexion angle in the sagittal plane.

Figure 5 depicts that the knee flexion patterns from initial foot contact to the point of maximum knee flexion were similar between the cases' affected side compared to the unaffected side.

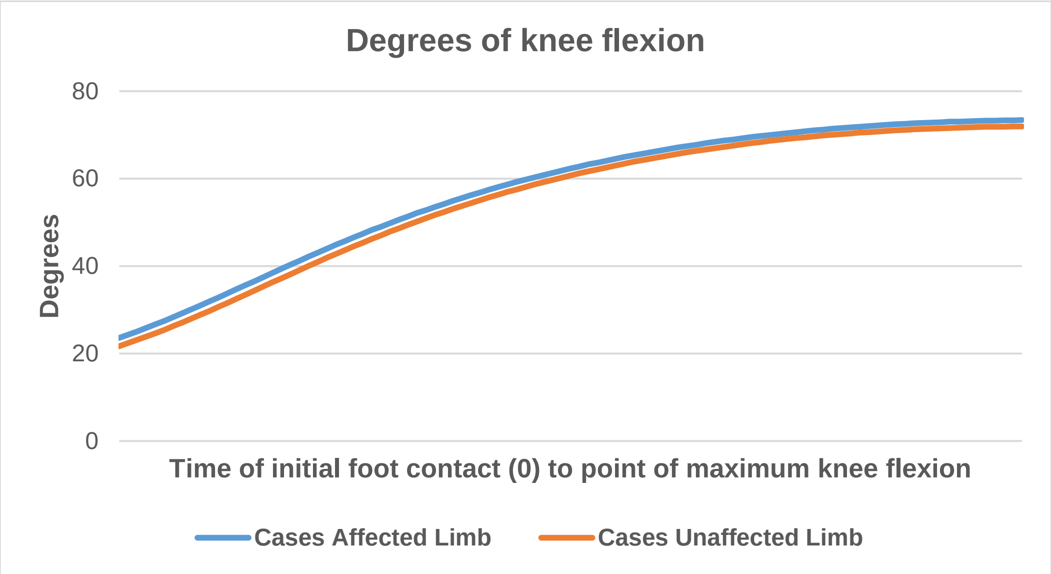

Figure 5: Cases' inter-limb comparison of knee joint flexion angle in the sagittal plane.

<u>Frontal Plane</u>

Figures 6 and 7 illustrate the difference in knee abduction from initial foot contact to peak knee flexion.

Figure 6 illustrates that the knee abduction from foot contact to the point of maximum knee flexion was more in the cases' affected side compared to the corresponding side of their matched controls.

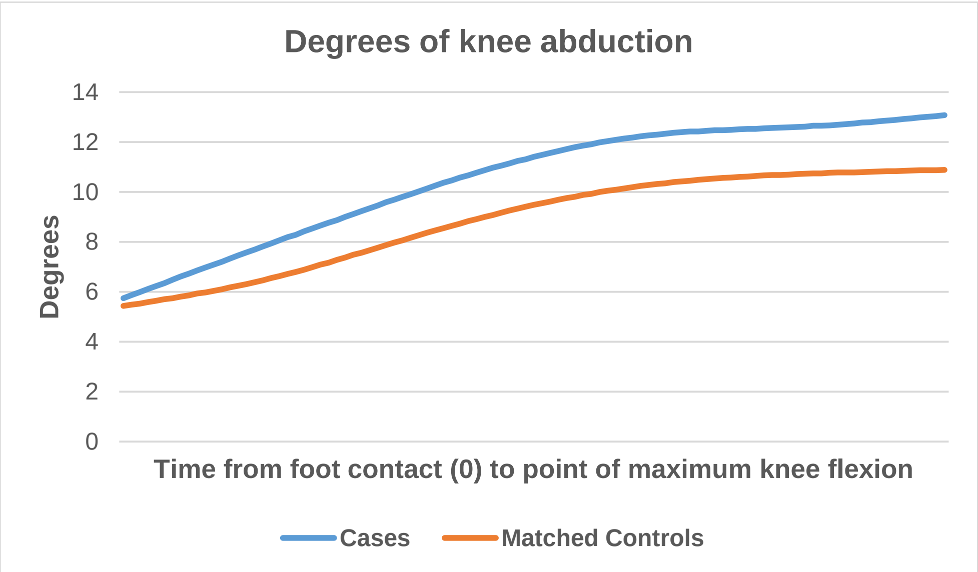

Figure 6: Cases' and their matched control comparison of knee joint flexion angle in the frontal plane.

Figure 7 depicts that the knee abduction patterns from initial foot contact to the point of maximum knee flexion were greater for the cases' affected side compared to the unaffected side.

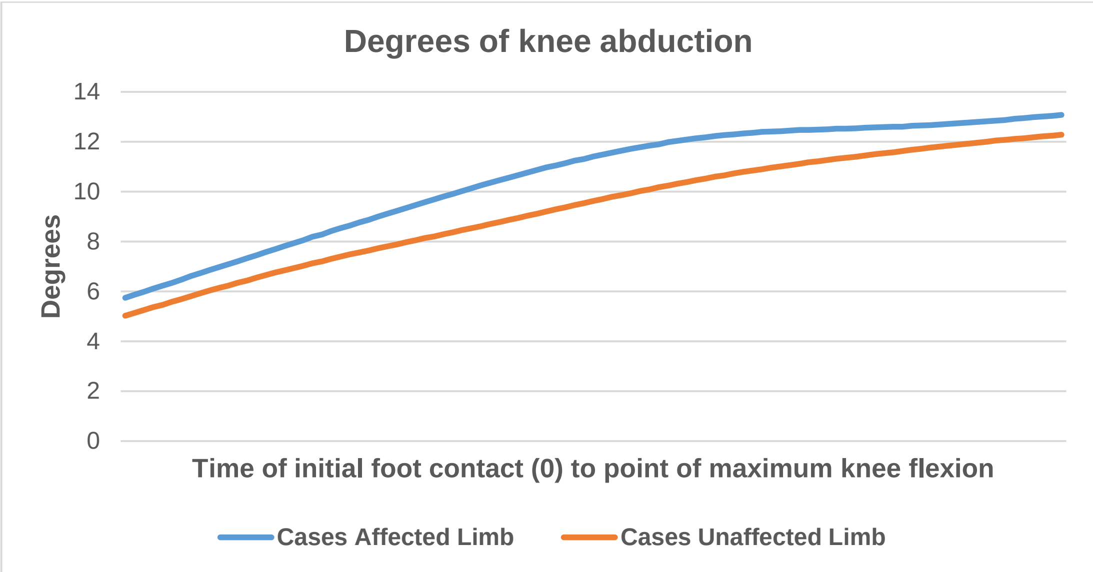

Figure 7: Cases' inter-limb comparison of knee joint flexion angle in the frontal plane.

<u>Transverse plane</u>

Figures 8 and 9 illustrate the difference in knee internal rotation from initial foot contact to peak knee flexion.

Figure 8 illustrates that the knee internal from initial foot contact to the point of maximum knee flexion was more in the cases' affected side compared to the corresponding side of their matched controls.

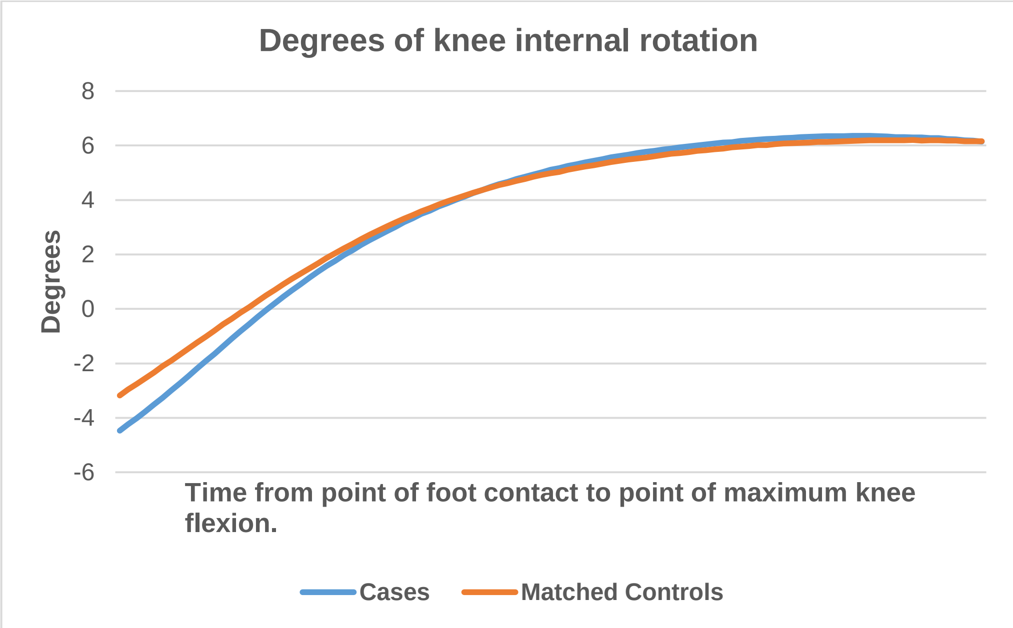

Figure 8: Cases' and their matched control comparison of knee joint internal rotation angle in the transverse plane.

Figure 9 depicts that the knee internal rotation patterns from initial foot contact to the point of maximum knee flexion were less for the cases' affected side compared to the unaffected side.

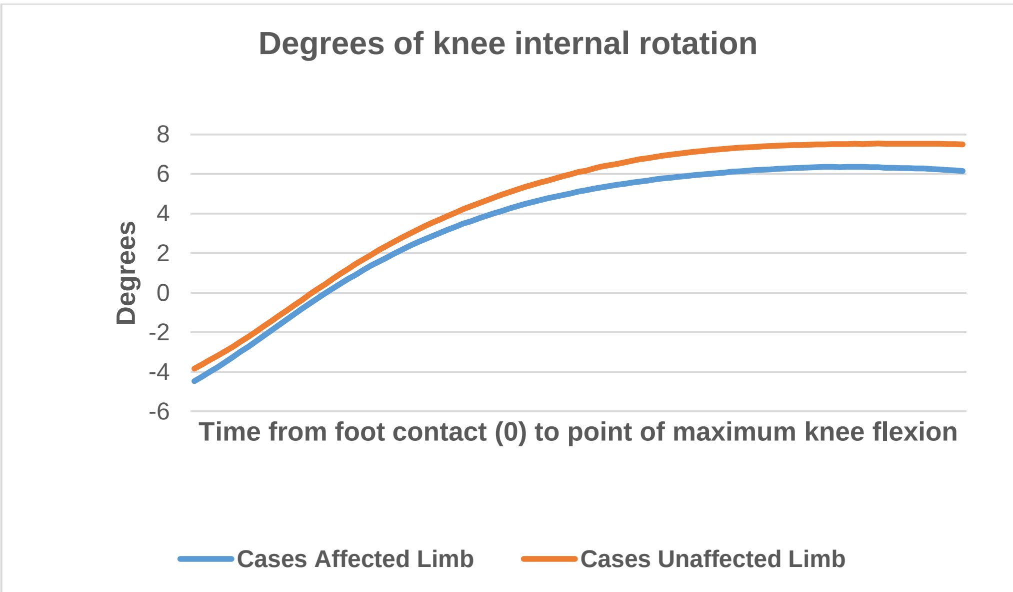

Figure 9: Cases' inter-limb comparison of knee joint internal rotation angle in the transverse plane.

CHAPTER 5

DISCUSSION

This study was aimed at determining the 3D kinematic differences of the knee joint of participants with chronic unilateral adductor-related groin pain compared to their asymptomatic matched controls, during the landing phase of the double leg jump.

Eighteen male participants (nine cases with chronic unilateral adductor-related groin pain and nine asymptomatic matched controls) who participate in running, rugby and soccer were included in this study. Verrall et al (2005) reported that rugby and soccer are weight bearing field sports which entails activities such as running, kicking and changing direction. Athletes participating in these football codes are more prone to develop groin pain, having an annual incidence rate of 12-16% per year (Morissey et al 2012; Whittaker et al 2015). Thus, the sample of participants were representative of the populations which are at a high risk of groin pain and injuries.

Cases were matched with asymptomatic controls in terms of sports participation, age and height. The matching of cases to their asymptomatic controls would ensure a more comparable activity performance as well as to control for known confounding factors.

The main finding of this study was that there were no statistical significant differences in the knee joint kinematics in cases compared to their asymptomatic matched controls, during the landing phase of the double leg jump. Furthermore no statistical significant difference in knee joint kinematics was noted in the inter-limb comparison in cases, during the landing phase of the double leg jump. It was hypothesised that there would be statistically significant kinematic differences of the knee joint when comparing athletes with chronic unilateral adductor-related groin pain and their asymptomatic matched controls as well as in the inter-limb comparison in cases, during the landing phase of the double leg jump. It was hypothesised that the affected lower limb of cases would present with increased multi-planar knee joint range of motion (ROM), during the landing phase of the double leg jump. This increased multi-planar knee joint ROM could be as a result of decreased knee control, during the landing phase of the double leg jump and could subsequently lead to energy absorption in a proximal to distal sequence.

In addition, there was a statistically insignificant tendency for the affected leg of cases to demonstrate more knee joint angulation in both the sagittal and frontal planes, during the landing phase of the double leg jump, in both the case-control and intra-limb comparisons.

It was found that the cases had 12.6 degrees larger knee flexion angle in the sagittal plane compared to their matched controls. This was a consistent, but statistically insignificant finding, which could be due to the small sample size. The increased the knee flexion angle, noted in the affected lower limb of cases, could possibly be attributed to a lack in eccentric control of the quadriceps muscle during the landing phase, which would result in increased muscle force activity of the hip adductors, in view of their sagittal plane synergistic role; i.e. assisting in hip flexion (Neumann 2010). In the presence of weaker VM and VL muscles the knee joint may present with less stability and present with increased multi-planar knee joint angulation (as reported by Flaxman et al 2012). In the CKC a lack of knee extension to absorb energy, in a distal to proximal sequence, can be compensated by a forceful co-contraction of the hip adductors during hip flexion, which would result in increased knee flexion and energy absorption in a top to bottom sequence (Karandiker & Ortiz Vargas 2011). It can therefore be hypothesised that repetitively employing a landing technique with increased knee joint sagittal plane kinematics during landing, can result in repetitive hip adductor muscle strain and subsequent development of chronic adductor-related groin pain.

In the frontal plane, it was found that the cases had 1.7 degrees greater knee abduction angle, compared to their matched controls. Although this was not a statistically significant finding, it corresponds with the amount of joint clearance in the knee joint frontal plane, which is controlled by the lateral ligamentous system of the knee and shortened hip adductor musculature (Yeow et al 2011). Frontal plane ROM are 8 degrees and 13 degrees, respectively with the knee in extension and 20 degrees knee flexion (Levangie & Norkin 2011). Within a CKC the motion of knee abduction is the product of hip joint adduction and internal rotation (Homan et al 2013). However, inversely a lack in knee joint stability, increases knee joint abduction and will result in an increase in the hip adduction angle (Järviven et al 2005). The increase in the hip adduction angle subjects the hip adductor muscle group to contract in an elongated position (Järviven et al 2005). Straining of the hip adductor muscle group could thus be considered to be as a result of the excessive tensile force in this elongated position in the absence of countering forces (Järviven et al 2005). It can be postulated that the repetitive contraction of the hip adductors in this elongated position could subsequently result in chronic adductor-related groin pain due to the repetitive stresses placed on the converging tendons of the adductor muscle group.

In the transverse plane, the affected limb of cases demonstrated increased knee external rotation ROM at initial foot contact in both the cases' inter-limb comparison and cases' and matched control comparison. The biomechanical principle of short lever muscles, such as the popliteus muscle, is that they have little ability to produce torque; the ROM produced in the transverse plane is very small (Stensdotter et al 2008). The internal rotation torque produced by the affected limb during the landing phase could be indicative of a lack of stability which is essential for locking of the knee joint. The knee joint requires a combination of inter-planar movement and contraction forces of its surrounding muscles in order to sustain the forces subjected to it during landing activities (Flaxman et al 2012). Bearing this in mind, the lack of stability in the transverse plane could result in increased knee ROM in the frontal and sagittal planes for the affected limb.

Although statistically insignificant, the findings of this study indicated that there was increased angulation in the frontal and sagittal planes in the affected leg of cases in both the case-control and inter-limb comparisons, during the landing phase of the double leg jump. The consistent statistical insignificant findings could be due to the small study sample size. However, the sample size was considered as acceptable, as it had a power calculation of 0.97 or 97%. Fitzer & Heckinger (2010) reported that a study sample power calculation of 0.9 or 90% only, is considered generally acceptable for clinical application.

The single leg jump-landing task have been more frequently used in previous groin pain and limb asymmetry studies, however the use of the double leg jump promotes even weight distribution and symmetry of the lower limbs (Hewit et al 2012b; Gore et al 2014; Smith et al 2015). The even weight distribution and symmetry of the lower limbs during the landing phase, would thus ensure simultaneous lower limb muscle activation and subsequent joint angulation to absorb the impact on landing (Hewit et al 2012b; Gore et al 2014; Smith et al 2015). This will enable the determination of asymmetrical abnormalities in either case-control or inter-limb kinematic studies. Hewit et al (2012a) reported that the double leg jump appeared to have a greater reliability in determining lower limb strength compared to single leg jumps, squat jumps and countermovement jumps. This was based on the reliable ICC values as reported by Walmsley and Amell (1996) of more than 0.75 and this indicator should be at least 0.90 in terms of clinical application (Hewit et al 2012a).Furthermore Yeow et al (2009) reported that employing a double-leg landing technique provides a stable base which was deemed as effective for improved impact shock reduction as the lower limb muscles generates internal muscle moments to counter joint motion, as a result of the impact.

There is a lack of research in the study of knee joint kinematics and its relation to groin pain. However former knee joint kinematic studies, employing double leg jump-landing task, have been conducted. Yeow et al (2009), Yeow et al (2010), Norcross et al (2013a), and Norcross et al (2013b) respectively reported on the kinematic, kinetic and energy dissipation effects of double leg jump-landing tasks on lower limb joints in the frontal and sagittal planes.

However these studies sought to determine the correlation between lower limb kinematics and lower limb joint injury potential. In addition these studies included healthy participants only, excluded inter-limb comparisons and studies by Norcross et al (2013a), and Norcross et al (2013b) did not include a homogeneous study sample.

Effective landing during sport is aimed at resisting joint collapse of the lower limb, as a result of accelerated hip and knee flexion, and ankle dorsiflexion as the body descends during a jump-landing task (Devita & Skelley 1992). The application of an external load, such as the impact force on landing of a jump-landing task, would require dissipation in a sequence from distal to proximal (Karandiker & Ortiz Vargas 2011). Knee joint stability is the result of multi-planar control (as reported by Flaxman et al 2012), i.e. the eccentric control of the quadriceps muscle reduces knee joint flexion and maintain tautness in the lateral knee joint ligaments to reduce knee joint abduction. The neuromusculoskeletal system is subjected to a considerable challenge in controlling multiple joints when exposed to the impact forces experienced during the landing phase of jumping (McNitt-Gray et al 2001). Therefore it can be considered that an imbalance or lack in the tensile forces produced by the muscles acting on the knee joint will result in knee joint instability and subsequent lesser energy absorption at the knee joint. The lack of energy absorption at the knee joint could thus result in energy transfer in a proximal to distal sequence, increasing the strain on proximal structures such as the hip adductors. It can thus be postulated that the lack of knee joint stability, based on increased multi-planar knee joint angulation, would result in increased proximal hip joint energy absorption. Thus increasing musculature activation around the hip joint and its attempts at absorbing energy on impact in a proximal to distal sequence. Muscles, such as the AL, which has a secondary role of as hip flexor and internal rotator, could potentially undergo strain as a result of the increased torque produced during the landing phase.

The lack in kinematic differences in the case-control and inter-limb comparisons of cases, as determined by this study, could be due to the level of sports participation. Participants for this study all participated in sports at club level, which would not influence their extent of neuromuscular training and sports activity compared to elite athletes (as reported by Gore et al 2014). Therefore cases and their matched controls would present with similar fitness level and symmetry and consequently the reason for non-significant findings. In their respective studies Rahnama et al (2005), McLean et al (1993) and Zahalka et al (2013) all reported on the inter-limb asymmetry in elite soccer players and kinematic differences (Gore et al 2014). They postulated that kinematic differences could potentially be demonstrated should elite soccer players be compared to normal healthy matched controls (Gore et al 2014). Schlitz et al (2009) reported that asymmetry in professional or elite athletes are likely as a result of their neuromuscular training and extent of their activity-related training (Gore et al 2014). Greater asymmetrical differences may be identified when comparing the elite athletic groin pain group to recreational level matched controls rather than to elite healthy athletes (Gore et al 2014).

CHAPTER 6

LIMITATIONS AND RECOMMENDATIONS

This study found no significant kinematic differences in cases with chronic unilateral adductor-related groin pain in the case-control and inter-limb comparisons, during the landing phase of the double leg jump. However the cases had a tendency to present with increased knee joint flexion and abduction range of motion in the case-control and inter-limb comparisons.

A limitation of this study was that were no hip joint kinematic data available which could be used in order to determine whether there is a relationship in abnormal hip joint and knee joint kinematics in cases.

Future research should compare cases with chronic unilateral adductor-related groin pain with matched asymptomatic non-athletic participants, or the study sample should consist only of elite athletes in order to identify greater kinematic differences. Alternatively future research should consist of a larger study sample in order to identify greater kinematic differences.

The observation that cases had a tendency to present with increased knee joint flexion and abduction range of motion indicates that this biomechanical model of assessment will be suitable in monitoring rehabilitation outcomes.

CHAPTER 7

CONCLUSION

The objective of this study was to determine whether there is a difference in knee joint kinematics in athletes with chronic unilateral adductor-related groin pain when compared to matched controls, when performing a double leg jump- landing task. The main finding of this study was that there was no statistical significant kinematic differences in the knee joint kinematics in cases compared to matched asymptomatic controls, during the landing phase of the double leg jump. In addition, there was no statistical significant differences in the knee joint kinematics in the inter-limb comparison in cases during the landing phase of the double leg jump. There was however a tendency for the cases to have increased knee flexion and knee abduction angles, from initial foot contact to the point of maximum knee flexion in both the case-control comparison and the inter-limb comparison.

The statistically insignificant knee joint kinematic differences could be due to the sample size of this study. Future research on this topic should consist of a larger study sample in order to determine kinematics differences. The level of sports participation of study participants should be defined clearer in future in order to determine statistically significant differences.

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APPENDIX A: LITERATURE SEARCH

The following key words were used for the literature search per database: *'groin pain', 'groin strain'*, *'adductor strain'*, *'chronic groin pain', 'chronic adductor strain', 'long standing groin pain', 'long standing adductor strain', 'knee* AND *(groin pain)'*, *'knee kinematics'*, *' landing* AND *(groin pain) '*, *'landing kinematics'*, *'knee* AND (*sagittal plane)'*, *'knee* AND *(frontal plane)', 'knee* AND *(transverse plane)', 'muscle strain', 'tibia AND (transverse plane)', 'knee AND (kinematic coupling)', 'tibia AND landing', 'EMG AND landing', 'EMG AND (lower extremity),* and *'popliteus muscle'.*

Studies were selected for this literature review based on whether reference was made to any or a combination of the following terms: *'groin pain', 'terminology of groin pain', 'definitions of groin pain', 'adductor related groin pain', 'adductor related groin strain'*, *'adductor muscle strain', 'chronic groin pain', 'chronic adductor related groin pain', 'diagnosing long standing groin pain', 'long standing adductor related groin pain', 'groin pain risk factors', 'knee joint muscles', 'groin strain risk factors', 'groin injury risk factors', 'assessing groin pain', 'differential diagnosis of groin pain', 'MRI findings and long standing adductor related groin pain', 'clinical tests and groin pain', 'management of groin pain', 'treatment of groin pain', 'landing kinematics'*, *'landing stiffness', 'joint kinematics'*, *'gender differences and landing kinematics', 'groin pain definitions', 'lower limb kinematics', 'knee kinematics', 'jump analysis', 'lower limb biomechanics', 'biomechanics and landing', 'EMG analysis and landing', 'knee and jump landing', 'knee and single leg landing', 'knee and double leg landing', 'knee and weight bearing', 'hip strength', 'hip abductor function', 'hip abduction weakness', 'hip muscle activation', 'leg asymmetry', 'asymmetry and jumping', 'knee kinematic models',* and *'kinematic chains'*.

All relevant articles had to be published in the English language as full text articles to be eligible for inclusion in this review. Exclusions were not made in terms of year of publishing, due to the paucity of relevant articles. In addition a secondary search were performed (pearling) by reviewing the reference lists of relevant articles for other potential references.

APPENDIX B: ADDUCTOR SQUEEZE TEST

The adductor squeeze test is a pain provocation test which has shown to have a 79% positive predictive value in screening for the incidence of adductor-related groin pain (Crow et al 2010). During the screening process, the participant was positioned in a crook-lying position with the arms folded across their chest. The participant's hips was positioned in 45º of flexion with both knees flexed to 90º (verified with a universal goniometer) and hips in neutral rotation. The same sphygmomanometer was used for all participants. The sphygmomanometer was pre-inflated to 10 mmHg and placed between the participant's knees. The middle third of the sphygmomanometer cuff was located at the most prominent point of the medial femoral condyles (as seen in Figure 10). The participant was then instructed to squeeze the cuff as hard as possible and maintain the squeeze for 10 seconds, before returning to relaxed position. The highest pressure value displayed on the sphygmomanometer dial was recorded during each maximal adductor squeeze test. A two minute rest period was allowed between each of the three trials. (Nevin & Delahunt 2014). The test would be considered valid in the presence of pain and decreased adductor squeeze test values for cases compared to their matched controls. Mens et al and Malliaras et al reported athletes with groin pain to have reduced adductor squeeze test values (Nevin & Delahunt 2014).

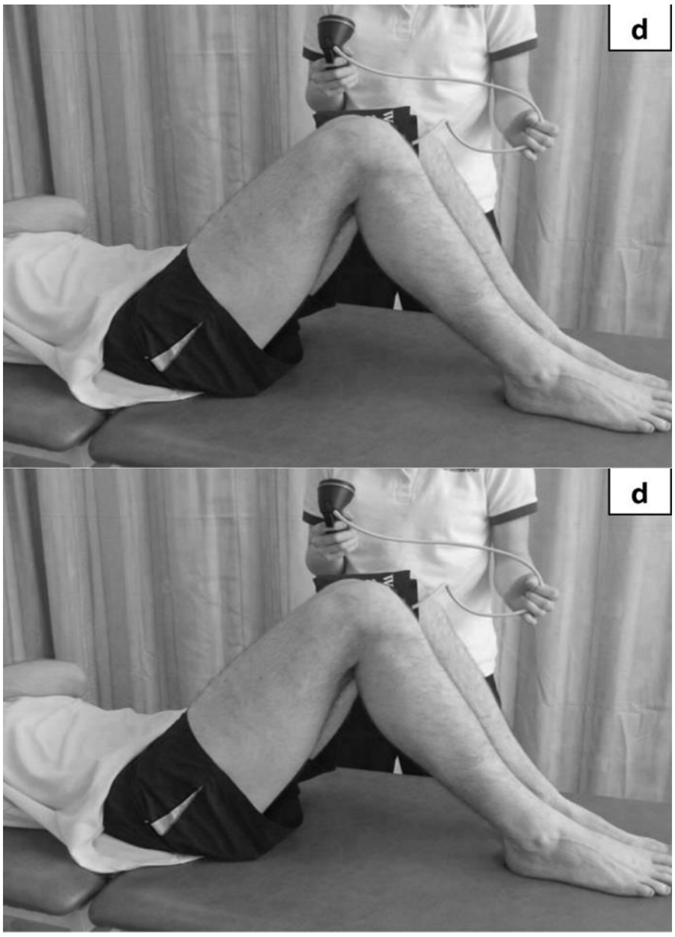

Figure 10: An image illustrating the adductor squeeze test.

Validity

Verrall et al (2005) reported that a positive adductor squeeze t is 95% predictive of chronic adductor-related groin pain when compared with bone marrow oedema seen on MRI. Similarly Mens et al (2002) deduced that the adductor squeeze test has the ability to associate hip adduction strength with disease severity in patients with Posterior Pelvic Pain since pregnancy (PPPP).

Reliability

The adductor squeeze test's intra- and inter-tester reliability was established as acceptable to good, with Pearson's correlation coefficient and the intra-class correlation coefficients (ICC) both = 0.79 (Mens et al 2002).

APPENDIX C: PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

The kinematic and kinetic differences in athletes with chronic adductor related groin pain.

REFERENCE NUMBER:

PRINCIPAL INVESTIGATORS	CONTACT NUMBER
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ADDRESS:

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You are herewith invited to participate in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study group any questions about any part of this project that you do not fully understand. It is very important that you clearly understand what this research entails and how you would be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you initially agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

The study will be conducted at the Physiotherapy and FNB-3D Movement Analysis Laboratory at Stellenbosch University, Tygerberg Campus, Cape Town. A total of 30 participants will participate in the study. Data capturing will be conducted over 6 sessions in groups of 5 on a predetermined date at a time.

The study is aimed at analysing the lower limb movements of soccer and rugby players that have chronic groin injuries and comparing them to players that are uninjured. This will allow for a greater understanding as to the possible causing/contributing factors of a groin injury.

Possible participants will be screened by two physiotherapists at their clubs and will then be invited to participate in the study at theFNB-3D Movement Analysis Laboratory. At the lab each participant will be booked for a particular time slot and then be allowed to familiarise themselves within the laboratory. The information sheet will be discussed again on the day of testing. Each participant will be asked to rate their current pain and their joint ranges of motion, weight, height and leg length will be measured before testing. Each participant will be asked to perform a maximum effort jump three times and to stand on one leg (pelican stance) at a time for 10 seconds and to repeat it three times. During this time the participants will be connected to external EMG electrodes to detect muscle activation patterns. The measurements will take approximately one hour.

Why have you been invited to participate?

You have been identified by your rugby /soccer club as being a suitable participant for this study as either a case or a control.

What will your responsibilities be?

You will be asked to participate in activities as mentioned above at the motion laboratory on a predetermined date for one day only.

Will you benefit from taking part in this research?

By participating in this study research in the field of chronic adductor related pain will be better understood and the future prevention and management strategies could be improved.

Are there in risks involved in your taking part in this research?

There are no risks involved in this study.

If you do not agree to take part, what alternatives do you have?

The study is based on analyses of movement; if you do not wish to participate you are free to withdraw at any stage with no needed alternatives.

Who will have access to your medical records?

Only the investigating team and related supervisors will have access to the results obtained from the study. Each participant will be allocated with an identification number thereby ensuring confidentiality. Consent will be sought for the publication of results and the use of photographs taken during the study and the identity of the participants will remain anonymous.

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

There are no anticipated risks for participating in this study; each participant is however participating at his own risk.

Will you be paid to take part in this study and are there any costs involved?

You will not be remunerated for participating in the study; however your transport will be covered for each study visit. There will be no costs involved for you, if you do participate.

Is there anything else that you should know or do?

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your researchers.
You will receive a copy of this information and the consent form for your own records.

Declaration by participant

By signing below, I …………………………………..………… agree to take part in a research study entitled: The kinematic and kinetic differences in athletes with chronic adductor related groin pain.

I declare that:

- I have read or had read to me this information and the consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study researcher feels it is in my best interest, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) …………..………. 2014.

....

Signature of participant   **Signature of witness**

Declaration by investigator

I *(name)* ……………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him to ask questions and took adequate time to answer them.
- I am satisfied that he adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) ....…........…………….. on (*date*) …………....……….. 2014.

....

Signature of investigator   **Signature of witness**

Declaration by interpreter

I *(name)* ……………………………………………..……… declare that:

- I assisted the investigator (*name*) ………………………………………. to explain the information in this document to (*name of participant*) ……………..……………………………….. using the language medium of Afrikaans/Xhosa.
- We encouraged him to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) ....…........…………….. on (*date*) …………..…… 2014.

....	....
Signature of interpreter	**Signature of witness**

APPENDIX D: ETHICS APPROVAL LETTER

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot · your knowledge partner

Ethics Letter

26-Jan-2015

Ethics Reference #: S12/10/265
Clinical Trial Reference #:
Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Ms Tracy MORRIS,

The HREC approved your application for a Protocol Amendment dated 2 October 2014.

Approval was also granted for the new research team for the extended study namely:

Principal Investigator:
PROF Q LOUW

M Students:
ERNESTINE BRUINDERS
WENDY-LYNN MOODIEN
ANICA COETSEE
CHARIS WHITEBOOI
CATHRINE DU PLESSIS

Supervisors:
DR SJAN MARI VAN NIEKERK
DR YOLANDI BRINK
MS GAKEEMAH INGLIS JASSIEM
MR JOHN COCKCROFT
DR MARIANNE UNGER
MS MARLETTE BURGER
MS LEONE WILLIAMSWILLIAMS

If you have any queries or need further assistance, please contact the HREC Office 219389156.

Sincerely,

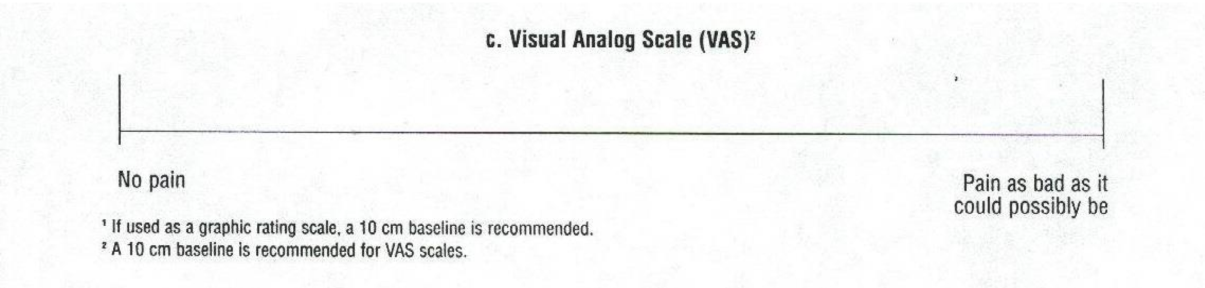
REC Coordinator
Franklin Weber
Health Research Ethics Committee 1

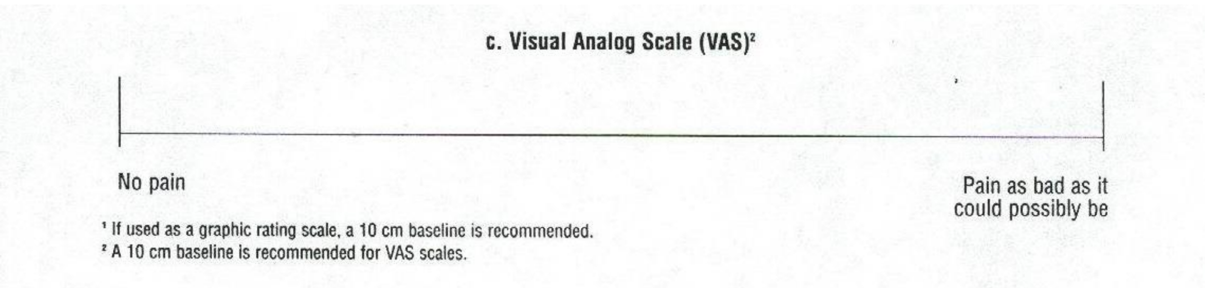
APPENDIX E: PARTICIPANT ASSESSMENT FORM

Participant:	
Sport:	
Date:	

VAS (Before tests)

Please indicate on the line the pain that you are CURRENTLY feeling:





<table>
<tr><td colspan="2">Height:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Weight:</td><td colspan="2"></td></tr>
<tr><td colspan="4" align="center">Leg length</td></tr>
<tr><td>Left:</td><td></td><td>Right:</td><td></td></tr>
</table>

<table>
<tr><td colspan="5" align="center">Joint width:</td></tr>
<tr><td>Knee:</td><td>Left:</td><td></td><td>Right:</td><td></td></tr>
<tr><td>Ankle:</td><td>Left:</td><td></td><td>Right:</td><td></td></tr>
</table>

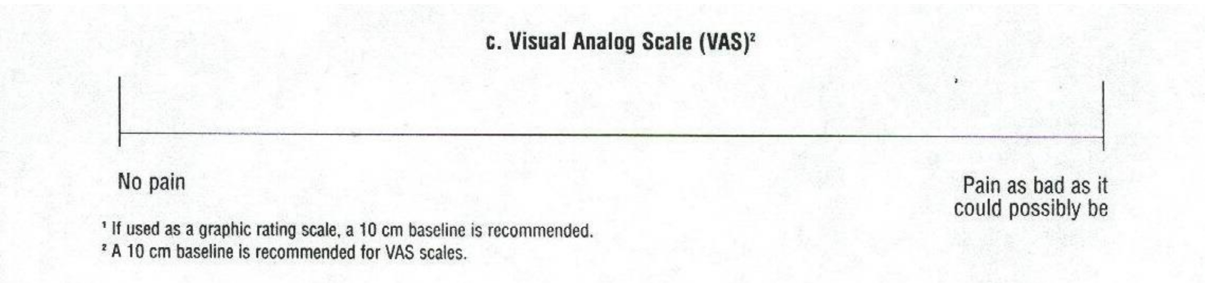
Hip	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Extension								
Flexion								
Abduction								
Adduction								
Internal Rotation								
External Rotation								

Knee	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Extension								
Flexion								

Ankle	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Dorsiflexion								
Plantar flexion								
Inversion								
Eversion								

VAS (After tests)

Please indicate on the line the pain that you are CURRENTLY feeling



APPENDIX F: RETRO-REFLECTIVE MARKER PLACEMENT

1. Placement of the pelvis markers:

- Left anterior superior iliac spine (ASIS)/ Right ASIS
  - Directly over the anterior superior iliac spines.
- Left posterior superior iliac spine (PSIS)/ Right PSIS
  - Directly over the posterior superior iliac spines.
- The Sacrum
  - The mid-point between the left and right PSIS.

2. Placement of the hip markers

- Left hip/ Right hip
  - Directly over the most prominent points of the greater trochanters.

3. Placement of knee markers:

- Left knee/ Right knee
  - The lateral epicondyle of the femur.

4. Placements of the tibia markers:

- Left tibia/ Right tibia
  - The lower lateral third of the tibia, to determine the alignment of the ankle flexion axis. The marker is placed in a line joining the knee and the ankle markers
    - The tibial marker should lie in the plane that contains the knee and ankle joint centres and the ankle flexion/extension axis.
    - A wand mounted marker may be used

5. Placement of the ankle markers:

- Left lateral malleolus (LLMAL)/ Right lateral malleolus (RLMAL)
  - The lateral malleolus along an imaginary line that passes through the trans-malleolar axis.
- Left medial malleolus (LMMAL)/ Right medial malleolus (RMMAL)
  - The medial malleolus of the ankle (only used during the Oxford correction static subject calibration).

6. Placement of the foot markers:

- Left toe (LTOE)/ Right toe (RTOE)
    - The second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot.
- Left heel (LHEE)/ Right heel (RHEE)
    - Place on the calcaneus at the same height above the plantar surface of the foot as the toe marker.
-